AMT Measurements for MODIS Calibration and Validation

Stanford B. Hooker
NASA Goddard Space Flight Center
SeaWiFS Project Code 970.2
Greenbelt, Maryland

Background and Introduction

Spectral water-leaving radiance, $L_W(\lambda)$, is the central physical quantity for bio-optical studies in the upper ocean. Whether determined from above- or in-water techniques, $L_W(\lambda)$ must be accurately determined, particularly for the vicarious calibration of a remote sensor. The work documented here is derived principally from the calibration and validation objectives of the SeaWiFS and MODIS Projects. Because the MODIS instrument was not launched until very recently (December 1999), the majority of the results are associated with SeaWiFS requirements. The general set of objectives involves characterizing and calibrating the SeaWiFS system; supporting the development and validation of algorithms for bio-optical properties and atmospheric correction; analyzing trends and anomalies in the derived products and sensor performance; selecting ancillary data sets which are used in data processing (e.g., winds, ozone, and atmospheric pressure); and verifying the processing code (McClain et al. 1992). The culmination of properly executing these responsibilities is achieving a radiometric accuracy to within 5% absolute and 1% relative, water-leaving radiances to within 5% absolute, and chlorophyll *a* concentration to within 35% (McClain et al. 1998).

The field activities discussed here include a) the British Atlantic Meridional Transect (AMT) Program, b) the Italian Coastal Atmosphere and Sea Time-Series (CoASTS), c) the French *Productivité des Systèmes Océaniques Pelagiques*† (PROSOPE), and d) SeaWiFS coastal campaigns for instrument validation. The AMT Program exploits the passage of the Royal Research Ship *James Clark Ross* (JCR) as it transits more than 100° of latitude between the UK and the Falkland Islands. In September, the JCR sails from the UK, and the following April it makes the return trip (Aiken et al. 2000).

CoASTS is a cooperative activity between the Joint Research Centre (JRC) and the Italian National Research Council (CNR). As part of the field campaigns, which started in October 1995 and continues to-date, atmospheric and marine measurements are periodically performed at the *Acqua Alta* Oceanographic Tower (AAOT). The tower is located in the northern Adriatic Sea approximately 15 km southeast of the city of Venice in approximately 17 m of water (Zibordi et al. 1999).

PROSOPE is a joint JGOFS–France Program based on a single (30-day) cruise aboard the research vessel *Thalassa* along a transect starting from Agadir (Morocco), then offshore along the North African coast in the Mediterranean Sea, and ending in the Ligurian Sea (north of Corsica). The primary objective was to sample a variety of trophic regimes, ranging from (upwelling) eutrophic systems, (coastal) mesotrophic regimes, and (central) oligotrophic waters (between Crete and Libya).

† Productivity of pelagic oceanic systems.

The SeaWiFS coastal campaigns are highly focused expeditions designed to address specific questions associated with optical data collection in the field. The idea is to dedicate the use of the ship(s) involved to answer the question(s) being posed, while collecting a high quality data set for calibration and validation activities. The first expedition took place at the Caribbean Marine Research Center (CMRC) in Lee Stocking Island (Bahamas) from February to March 2000 and was concerned with validating the performance of a new in-water profiler. The second campaign took place at the Harbor Branch Oceanographic Institute (HBOI) in Ft. Pierce (Florida) from April to May 2000 and was concerned with refining above-water methods for measuring water-leaving radiance.

Open Ocean Measurements

One of the important accomplishments in the AMT Program was quantifying the total uncertainty budget for a variety of in-water optical instruments. A comprehensive approach was undertaken and included a) the use of a portable light source, the SeaWiFS Quality Monitor (SQM), to monitor the calibration stability of the instruments in the field (Jonhson et al. 1998); b) in-water intercomparisons to independently assess the conclusions derived from the SQM; c) alternative methods for acquiring solar reference data (deck cells, drifting buoys, etc.); and d) different techniques for making in-water profiles (winched versus free-fall systems). The instruments used for the uncertainty analyses included the SeaWiFS Optical Profiling System (SeaOPS), the Low-Cost NASA Environmental Sampling System (LoCNESS), and the SeaWiFS Free-falling Advanced Light Level Sensors (SeaFALLS). The former is deployed from a winch and crane, whereas, the latter two are floated away from the ship and deployed by hand; all were built by Satlantic, Inc. (Halifax, Canada).

Both SeaOPS and LoCNESS are modular 7-channel systems, i.e., they are built up from (relatively) inexpensive 16-bit components externally cabled together. SeaFALLS and its reference sensors are comparatively more expensive, because they use gain switching, 24-bit A/D conversion, and integral 13-channel sensors—they cannot be easily disassembled or reconfigured. All of the profiling instruments measure $L_u(\lambda)$ and $E_d(\lambda)$, but SeaOPS can also measure $E_u(\lambda)$.

The LoCNESS profiler was developed by the SeaWiFS Field Team and Satlantic as an inexpensive alternative to SeaFALLS, but also as a more capable instrument: it is built from the SeaOPS components and can be configured with the Three-Headed Optical Recorder (THOR) option (Aiken et al. 1998). In the THOR configuration, an adapter plate is used on the nose to mount the usual $L_u(\lambda)$ sensor plus an additional $E_u(\lambda)$ sensor. The two nose sensors do not disturb the stability of the profiler during descent. In fact, THOR has the smallest and most stable tilts of all the profilers, because of its length (1.78 m) and

Table 1. The quantification of total measurement uncertainties as a function of the various deployment systems used in the AMT Program. The systems are shown with their reference configurations. Only SeaFALLS was used with multiple references: the SeaBOSS configuration is SeaBOSS deployed as a buoy, and the deck cell configuration is SeaBOSS on a mast.

Source of Uncertainty	*SeaOPS w/Deck Cell*	*LoCNESS w/Deck Cell*	*SeaFALLS w/SeaSURF*	*SeaFALLS w/SeaBOSS*	*SeaFALLS w/Deck Cell*
Calibration	1.5%	1.5%	2.0%	2.0%	2.0%
Data Processing	2.0	2.0	2.0	2.0	2.0
In Situ Stability	1.0	1.0	1.0	1.0	1.0
Data Collection	2.0	0.5	4.0	2.0	1.0
Quadrature Sum	3.4%	2.7%	5.0%	3.6%	3.2%

the large surface area of the fins. This stability, and the fact that three components of the light field are measured, makes it one of the most versatile profilers in use today.

Incident solar irradiance data are provided by three instruments. SeaOPS and LoCNESS are deployed in parallel with a 7-channel in-air irradiance sensor mounted on a mast (the so-called *deck cell*). SeaFALLS has two references: the SeaWiFS Square Underwater Reference Frame (SeaSURF), which is composed of an in-water irradiance sensor suspended below a tethered, square floating frame; and the SeaWiFS Buoyant Optical Surface Sensor (SeaBOSS), which is an in-air irradiance sensor fitted inside a removable buoyant collar, so it can be deployed on a mast (as a deck cell) or as a tethered buoy.

Table 1 presents a summary of the total uncertainty budget for the AMT in-water instruments (Hooker and Maritorena 2000). The entries are average values corrected for deterministic problems identified in the original study, e.g., if the SQM analyses showed a particular sensor had an incorrect calibration, the data collection uncertainty for the sensor was recalculated assuming the corrected calibration. The main differences in the levels of uncertainty for each source are in calibration and data collection. The 24-bit systems (SeaFALLS) have demonstrably higher noise†, so the calibration entries for these instruments are larger than for the 16-bit systems (SeaOPS and LoCNESS). The data collection uncertainties show the widest range of values with different explanations for each system: SeaFALLS equipped with SeaSURF is the largest because of the problem with wave focusing effects on a shallow, submerged sensor; SeaOPS and SeaFALLS equipped with SeaBOSS are next largest because of ship shadow contamination for the former and wave motion variance for the latter; LoCNESS and SeaFALLS with deck cells are the best with minimal uncertainties. Figure 1 shows the at-sea use of the SeaWiFS optical instruments [see Hooker and McClain (2000) for more details].

† The problems with the 24-bit instruments were detected and quantified with the SQM (Hooker and Aiken 1998), although there were aspects of the problem already known to the manufacturer.

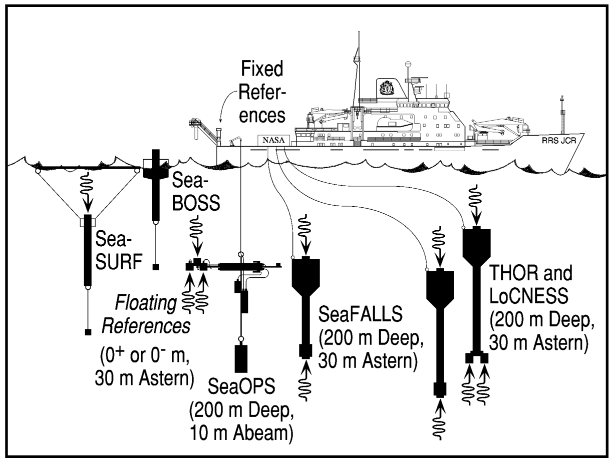

Fig. 1. Some of the in-water systems used by the SeaWiFS Field Team for open ocean sampling. The deployment distances to depth and away from the ship are shown in parentheses.

Although uncertainties can fortuitously cancel under some circumstances, and in a worst-case scenario can simply add together, a more realistic procedure is to sum the squares of the uncertainties and report the square root—the so-called *quadrature sum*. If this is done, all of the deployment systems have an uncertainty within the 5% level. The latter is particularly important, because if the field instruments do not achieve an uncertainty level below 5%, there is no margin of uncertainty for the spaceborne sensor if a total 5% uncertainty level is to be maintained for a vicarious calibration exercise (remote plus *in situ* instrumentation). Based on this more realistic set of criteria for the field instruments, LoCNESS, SeaOPS, and SeaFALLS with a deck cell all perform within acceptable limits with LoCNESS performing the best and only using up a little more than half of the 5% uncertainty budget (2.7%).

It is worth noting that despite the great deal of care taken in all facets of the *in situ* optical measurements (calibration, shipping, handling, deployment, radiometric monitoring with the SQM, data processing, etc.), the analysis reveals that in the worst case (all uncertainties summing together), the limit of the acceptable level of uncertainty (5%) has been reached. With slightly less attention to any step in the measurement process, it is likely the total uncertainty would increase beyond an acceptable level.

Coastal Ocean Measurements

Although the SeaWiFS Project has emphasized in-water calibration and validation exercises, there are disadvantages with them which are not present in above-water methods, e.g., the self shading of the instrument (Gordon and Ding 1992). Not surprisingly, the latter present new problems not present in the former, so there is a danger of simply swapping one set of problems for another. The possibility of taking data while underway and sampling in a shorter amount of time, however, makes the above-water instruments too useful to be ignored. The SeaWiFS Field Team has been incrementally engaging in above-water measurements with the objective of extracting the largest amount of validation data from both measurement types.

The uncertainty associated with above-water measurements has not been well quantified. The main difficulty is associated with correcting the observations for surface wave effects, which introduce significant fluctuations in the glint and reflected skylight components of the surface radiance field. The difficulty is compounded by the presence of clouds which increase the fluctuations and associated uncertainties. Case-2 waters represent yet another level of difficulty, because the number and spatial heterogeneity of bio-optically active constituents which do not co-vary with chlorophyll *a* concentration increases. Further compounding the measurement problems are the perturbations of the measurement platform (minimized with in-water measurements by the use of free-fall profilers).

The scientists investigating the in- and above-water measurement issues were called the first SeaWiFS Bio-Optical Algorithm Round-Robin (SeaBOARR) Team, because the ultimate objective is to evaluate the effect of different measurement protocols on bio-optical algorithms using data from a variety of field campaigns and deployment platforms. SeaBOARR-98 took place on the AAOT platform (Hooker et al. 1999) and SeaBOARR-99 took place on the JCR during the AMT-8 cruise (Hooker and Lazin 2000). The main reasons for selecting the AAOT for SeaBOARR-98 were as follows: a) it can accommodate the simultaneous deployment of a large number of instruments; b) its stability (towers do not pitch and roll like ships); c) the perturbative effects of the tower on the in-water light field were being studied and modeled, so a correction scheme was possible (Zibordi et al. 1999); and d) its proximity to a strong coastal front, so the water around the tower can be Case-1 or Case-2. The opportunity for sampling different water types within one field campaign was very appealing. Most of the SeaBOARR-98 data were collected in Case-2 water, so the decision was made to use AMT-8 for the second SeaBOARR deployment to ensure data collection in Case-1 waters.

The in-water instruments used during open ocean cruises are not necessarily the most appropriate for the shallow coastal environment. The water in the vicinity of the AAOT is approximately 17 m deep, and because Case-2 conditions predominate, large instruments have a significant self-shading problem. There is too the problem that in Case-2 waters where the heterogeneity both horizontally and vertically can be large, the light sensors should be as close to the same depth as possible. To address these problems at a reasonable cost, the SeaWiFS Field Team developed a miniature version of LoCNESS called miniNESS (Fig. 2). The miniNESS profiler measures $L_u(\lambda)$ and $E_d(\lambda)$, but rather than mount the light sensors on the nose and tail, they are mounted on the fin edges. Internal tilt sensors quantify the vertical orientation of the profiler as it falls through the water.

Fig. 2. A side-by-side comparison of three of the free-falling profilers discussed in this proposal: THOR (back) is 1.78 m long, SeaFALLS (middle) is 1.24 m long, and miniNESS (front) is 0.73 m long.

Mounting sensors on the fins destabilizes the profiler (although, tilts less than 2° have been regularly achieved by carefully trimming the profiler), and it makes the L_u sensor more susceptible to shading. This problem was minimized by choosing where the mechanical termination was with respect to the sensors and the sun. The two sensor fins, which are 180° apart, will align perpendicular to the mechanical termination when the cable is pulled in to bring the profiler to the surface (before a profile). To minimize L_u shading, all that is required is to choose which of the other two fins should be used for the mechanical termination, so the L_u sensor aligns towards the sun.

Although the miniNESS profiler is more appropriate for coastal sampling than LoCNESS or SeaFALLS, it is still bulkier than what is needed for small boat and shallow water operations. The size restrictions of miniNESS and its predecessors is a direct reflection of the current state of the art. The SeaWiFS Field Team has been developing an even smaller next-generation profiler with Satlantic called microNESS. To further decrease the size of the instrument system, and to solve many of the problems associated with the present technology, one of the first accomplishments for the new system was the development of a new smaller, completely digital, optical sensor. This new type of optical instrument is referred to as the 500 series (Fig. 3).

Fig. 3. A comparison of a new 4-channel OCI-500 digital reference (left) and a traditional 7-channel reference (right) based on an OCI-200.

The new sensors are available in 4- and 7-channel versions (504 and 507, respectively). The former are the smallest and are the ones used with microNESS; the latter is used for a solar reference. The 504-series sensors have the following characteristics:

a) A dynamic range of 18 bits;
b) A 4.6 cm diameter and a 9.4 cm long plastic housing (200-series sensors have a 9.4 cm diameter and a 10.9 cm length without any A/D capability);
c) Digital output (A/D conversion is done in the optical sensor); and
d) A 200 g weight (200-series sensors weigh approximately 1.1 kg).

Qualitative free-fall and recovery tests were conducted on rough 1:8 scale models. These small-scale tests were performed as a low-cost means of developing some intuitive understanding of the factors affecting the profiler's dynamics. Based on the model tests, some theoretical modeling of the profiler's dynamics, and the results of the development of the 500-series of optical sensors, a final configuration for microNESS was produced:

1. Operation from two 9 V lithium batteries (power hibernation possible);
2. A Paroscientific pressure sensor (0.01% full scale or about a 1 cm accuracy);
3. Two-axis tilt sensors and external temperature sensor;
4. A PVC 3.8 cm pressure case with a 450 m implosion depth (the OCR-500 has a 680 m implosion depth);
5. The traditional DATA-100 is replaced with a network or hub (supporting 127 nodes);
6. Dual fins with Rohacell foam;
7. A sampling rate of 6 or 12 Hz (the older instruments use 6 Hz); and
8. The traditional deck box is replaced by a modem which communicates with the logging computer via an RS-232 protocol.

It is important to note the increase in sampling rate and the use of a very accurate pressure sensor increases the vertical resolution of microNESS over previous profilers by an order of magnitude.

The other JRC optical instrument used on the AAOT, is the Wire-Stabilized Profiling Environmental Radiometer (WiSPER) package. WiSPER is permanently mounted on the AAOT and makes the same measurements as the JRC miniNESS, but it is winched up and down the water column between two taught wires, so it has no need for tilt sensors. The major advantage of this system is it can measure very close to the surface, and the low winch speed ensures excellent vertical resolution; the major disadvantage is it is sited within the shading effects of the tower.

The SeaSAS instruments measure the spectral indirect (or sky) radiance reaching the sea surface, $L_i(0^+,\lambda)$, and the (total) radiance right above the sea surface, $L_T(0^+,\lambda)$. The latter is composed of three terms: the radiance leaving the sea surface from below (the water-leaving radiance), the direct sunlight reflecting off the surface (the sun glint), and the indirect skylight reflecting off the surface (the sky glint). SUnSAS makes the same measurements as SeaSAS, but the surface-viewing radiometer looks through a square aperture that can be blocked with a calibrated (usually gray) plaque, so it can also measure the radiance of the plaque, $L_p(0^+,\lambda)$. The other major difference is the SUnSAS frame is compact with several limitations in its viewing or pointing aspects, whereas the SeaSAS frame is large with very few restrictions.

SeaSHADE is another new instrument developed by the SeaWiFS Field Team with Satlantic. It is composed of two separate sensors: one is used to measure the total or global solar irradiance just above the sea surface, $E_d(0^+,\lambda)$, and the other is equipped with a motorized shadow band that periodically occults the irradiance sensors so the indirect (or diffuse) solar irradiance, $E_i(0^+,\lambda)$, can be measured. SeaSHADE was developed, so the E_d/E_i ratio can be used in the calculation of the self-shading correction for the in-water instruments (Zibordi and Ferrari 1995).

The SeaWiFS Photometer Revision for Incident Surface Measurements (SeaPRISM) was conceived by the SeaWiFS Field Team, and developed by the JRC and CIMEL Electronique (Paris, France). SeaPRISM is based on a CE-318 sun photometer which is an automatic system that measures the direct sun irradiance plus the sky radiance in the sun and almucantar planes. The revision to the CE-318 that makes the instrument useful for ocean color calibration and validation is to include a capability for measuring the sea surface. What makes this instrument particularly powerful is it can operate autonomously, so a sampling site can be continuously monitored in between field campaigns that completely characterize the bio-optical conditions of the site.

In addition to paying close attention to the optimal viewing capabilities of each system, some instruments were equipped with sensors that measured their viewing angles. SeaSAS and SUnSAS, for example, use an external module developed by the SeaWiFS Field Team and Satlantic which measures the vertical (two-axis) tilts and horizontal (compass) pointing of the radiometers.

Results and Achievments

The benefit of the attention to radiometric metrology has been very good agreement between a variety of the optical data products. A least-squares regression of the chlorophyll *a* concentration estimated from water samples versus that estimated from the *in situ* light field for the AMT-5 through AMT-8 cruises (a time period covering the start of SeaWiFS operation to the middle of 1999) has a slope of 1.050 and an R^2 value of 0.966. The former was determined using the HPLC method, and the latter from the SeaWiFS OC2v2 algorithm (O'Reilly et al. 1998). A least-squares regression of the $L_W(\lambda)$ values determined from simultaneous deployments of the SeaFALLS and LoCNESS instruments during PROSOPE (synchronized through the use of multiple deployment teams equipped with radios) has a slope of 1.016 and an R^2 value of 0.995. Agreement at the approximately 2% level is very close to the calibration uncertainty between the two sampling systems and represents the limit of intercomparability.

The PROSOPE cruise sampled the eutrophic upwelling off northwest Africa (UPW), the oligotrophic Eastern Mediterranean (MIO), and a mesotrophic coastal site (DYF). A comparison of the PROSOPE field data with a large database derived from AMT cruises plus the corresponding model and satellite values, shows the (oligotrophhic) Mediterranean Sea is significantly different than the algorithm would predict, and that the SeaWiFS retrievals will result in a large overestimation of chlorophyll *a* (Fig.4). Although the OC2v2 algorithm and its subsequent revision (OC2v4) were determined from a large database, the low chlorophyll part was not as well sampled as the higher chlorophyll parts, so there is a possibility of bias in the algorithm, and the AMT data suggest this is part of the problem. The PROSOPE data taken in the (Atlantic) upwelling region agree with the model and the AMT database. The OC4 algorithm, which was determined from the same database as OC2, shows the same result: *there is a clear indication the Mediterranean Sea is distinctly different, which suggests a need for (large-scale) regional algorithms.*

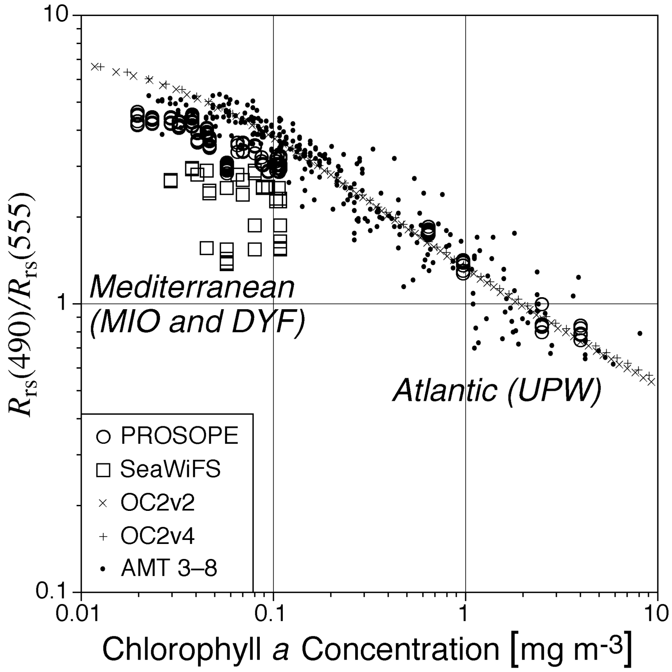

Fig. 4. A comparison of the ratio in remote sensing reflectance for 490 and 555 nm, $R_{rs}(490)/R_{rs}(555)$, as a function of *in situ* chlorophyll *a* concentration.

During SeaBOARR-98, the AAOT was used to compare water-leaving radiances derived from simultaneous above- and in-water optical measurements (Hooker et al. 1999). The former involved two different above-water systems and four different surface glint correction methods, while the latter used three different in-water sampling systems and three different methods (one system made measurements a fixed distance from the tower, 7.5 m, another at variable distances up to 29 m away, and the third was a buoy sited 50 m away). Instruments with a common calibration history were used, and to separate differences in methods from changes in instrument performance, the stability (at the 1% level) and intercalibration of the instruments (at the 2–3% level) was performed in the field with a second generation SQM (the so-called SQM-II).

The water-leaving radiances estimated from the methods, were compared during clear and overcast skies, Case-1 and Case-2 conditions, calm and roughened sea surface. Two different analytical approaches, based on the unbiased percent difference (UPD†) between the methods, were used to compare the different methods. The first used spectral averages across the 412–555 nm SeaWiFS bands, and the second used the ratio of the 490 and 555 nm wavelengths. The primary conclusions of the comparisons are as follows (Hooker et al. 2000): 1) the 5% radiometric objective is achieved for some in-water methods in Case-1 waters for both analytical approaches; 2) the 5% radiometric objective is achieved for some above-water methods in Case-2 waters for both analytical approaches, and achieved in

† The UPD for two variables X and Y is $200|X-Y|/(X+Y)$.

both water types for the normalized approach; 3) above- and in-water methods not specifically designed for Case-2 conditions are capable of results in keeping with those suitable for the Case-2 environment or in keeping with results achieved in Case-1 waters; 4) there is a significant difference between two above-water instruments oriented perpendicular with respect to the sun, but pointed in the same direction (best agreement) versus the opposite direction (worst agreement); and 5) the overall intercomparison of all methods across Case-1 and Case-2 conditions is at the 9.1% level for the spectral differences, and at the 3.1% level for the ratio differences (average non-methodological uncertainties account for 2–4% and 1–3% of these values, respectively).

Most of the data collected during SeaBOARR-98 was in Case-2 conditions, so one of the questions left unresolved was whether or not the results were typical for Case-1 conditions. Figure 5 presents an intracomparison of the water-leaving radiances derived from the above- and in-water optical systems used during PROSOPE, and shows they agree to within approximately 8.2%, with the majority of the data agreeing to within 5% (the SeaWiFS radiometric objective). The above- and in-water data were processed using the best protocols identified in the SeaBOARR-98 analysis. This is very similar to the results achieved in the northern Adriatic Sea in predominantly Case-2 conditions.

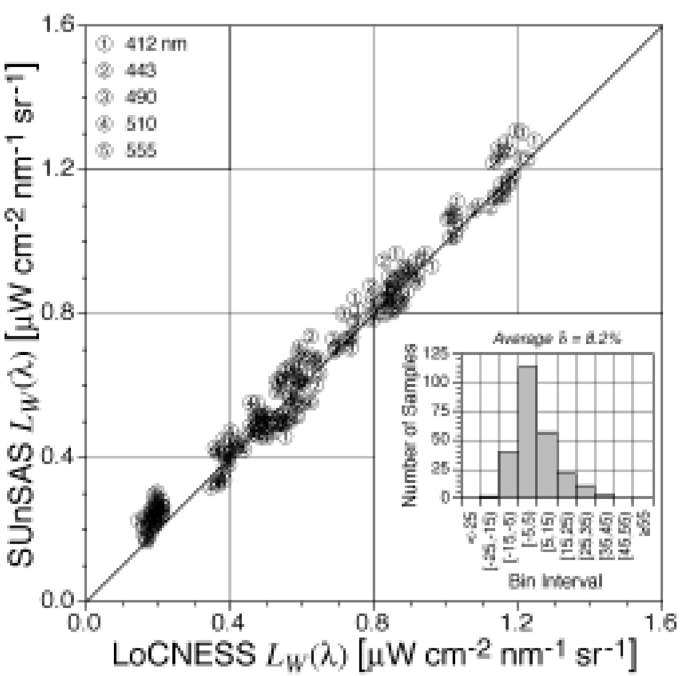

Fig. 5. A comparison of $L_W(\lambda)$ derived from above- and in-water methods (SUnSAS and LoCNESS, respectively,) during the PROSOPE cruise. The δ parameter is the UPD between the two data sets.

In terms of above-water measurements, there are several methods for glint correction which were developed for different conditions, i.e., clear or cloudy sky, and Case-1 or Case-2 water: Austin (1974); Morel (1980); Carder and Steward (1985); Bukata et al. (1988); Mueller and Austin (1995), the so-called SeaWiFS protocol; Lee et al. (1996); and Lazin (1998). All of the methods recognize the importance of making surface measurements free of sun glint effects, so the differences in the methods are primarily due to how sky glint is removed from the surface signal. What is not well quantified is the effect of the sensor's field of view (FOV) on the various correction methods. The importance of this issue is well demonstrated in Fig. 6, which compares the $L_T(490)$ values from two sensors with different (half-angle) FOVs that were mounted on a bar, so they could view the same area of the sea surface.

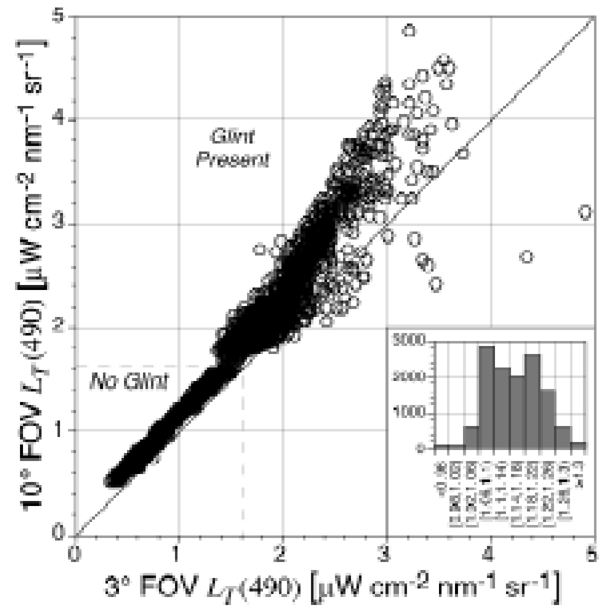

Fig. 6. A comparison of the $L_T(490)$ values determined from two SAS sensors: one with a 3° FOV, and one with a 10° FOV.

The data is separated into glint-free and glint-contaminated regimes (sensors pointed 90° away from, and into, the glint pattern, respectively). For the former, the larger FOV sensor overestimates $L_T(490)$, but the relationship with the smaller FOV sensor is mostly linear, suggesting the possibility of a simple correction scheme; for the latter, the relationship between the two instruments is very nonlinear with many different types of relationships, including the smaller FOV instrument measuring higher than the larger FOV instrument (in these cases, the smaller FOV sensor views only glint, whereas the larger FOV instrument views glint and non-glint, so the effective radiance is reduced).

Instrument FOV is one factor effecting the discretization of gradients and spikes in the medium being measured, like sky radiance or sun glint, respectively (sampling frequency is another). The protocols do not address the deployment heights (above the sea surface), so an alternative way to consider this problem is to consider posing it as a *spot size* effect. That is, if a particular FOV is being used, what is the proper deployment height above the sea surface for that particular FOV? To exploit the technology developed for the microNESS profiler, the SeaWiFS Field Team is developing a next-generation SAS instrument with a gimbaled reference and a changeable aperture called microSAS. The currently available sensors do not easily accommodate alternative apertures, because smaller FOVs would produce instruments that would be too large for easy deployment. The microSAS changeable aperture will permit 0.75° or 1.5° half-angle FOVs without negatively effecting deployment practices (Fig. 7).

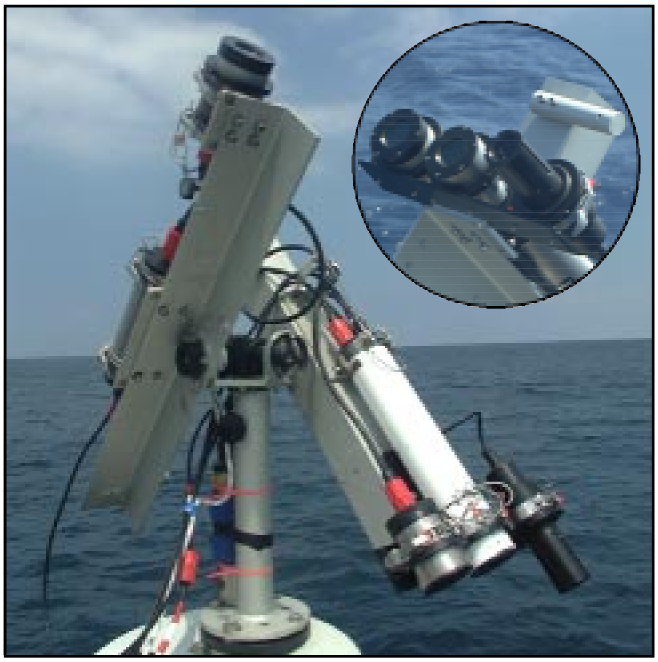

Fig. 7. The new microSAS instrument with the 0.75° half-angle FOV gershun tube extension (rightmost, long black sensor in both views) mounted on the SeaSAS frame during the SeaWiFS second coastal campaign along with two other SAS sensors with wider FOVs.

The continuing investigation of above-water methods has been complemented by the recent field validation of the microNESS profiler. This work was carried out in the Bahamas, and although microNESS was not fully operational, enough of the system was functioning to demonstrate the capabilities of the new design: a) the free-fall aspects of the profiler are excellent, b) the profiler is extremely well suited for small boat operations, and c) the light sensors meet or exceed their design objectives. The latter point is particularly important and was determined not only from simultaneous *in situ* comparisons with miniNESS, but also from SQM-II data (all sensors were monitored in the field).

A validation of the new SeaPRISM instrument with the WiSPER system was performed from 2–6 August 1999. As part of the validation experiment, a comparison of water-leaving radiances derived from WiSPER, SeaPRISM, and SIMBAD (a hand-held above-water radiometer) was made. SIMBAD attempts to deal with the negative effects of glint at the point of measurement (Fougnie et al. 1999), but SeaPRISM, like most methods, attempts to deal with glint explicitly by filtering it out or removing it with a correction algorithm. Three channels common to all three instruments were compared. The SeaPRISM data agree best with respect to the in-water data in terms of the UPD than the SIMBAD data: 8.6% for the former versus 13.9% for the latter (Fig. 8). The blue-green SIMBAD data is significantly shifted away from the 1:1 line, but the slope of the shift is correct, so the difference is more indicative of a bias. The latter could be due to a calibration problem or a problem with the glint correction scheme. Histograms of the UPD with respect to the in-water data show both the SeaPRISM and SIMBAD data agree well if the blue/green ratio is considered rather than the spectral average: 4.0% for the former and 3.1% for the latter.

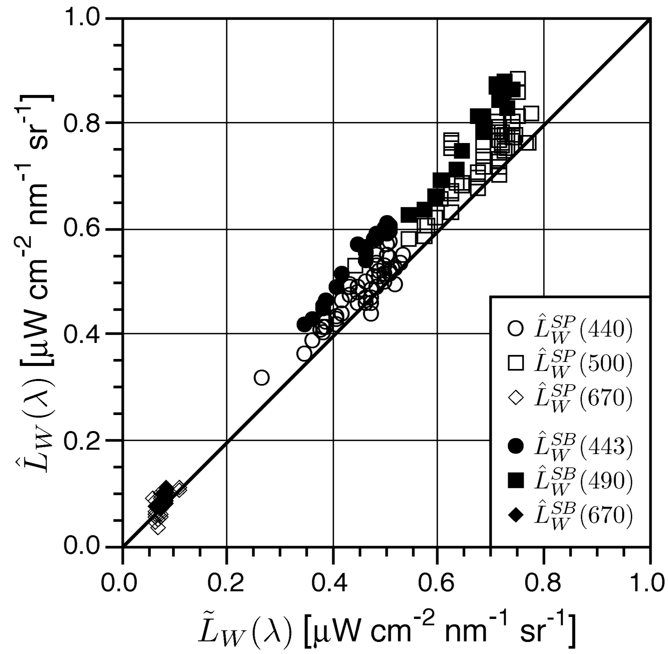

Fig. 8. A comparison of the water-leaving radiances from SeaPRISM ($\hat{L}_W^{SP}$) and SIMBAD ($\hat{L}_W^{SB}$) versus WISPER ($\tilde{L}_W$).

Planned Activities and Schedule

Although the AMT Program produced a state-of-the art optical data set (Hooker and Maritorena 2000), and has been used for an independent confirmation of the SeaWiFS Project's validation results, there was an important deficiency in the program that was intrinsic to the opportunistic structure of the sampling: the amount of optical data collected as a function of the effort to deploy to the field on a daily basis was not maximized. Figure 9 is a plot of the amount of above- and in-water optical casts collected in two types of campaigns: lengthy oceanic transits on a large research vessel (AMT and PROSOPE) and shorter day trips on small boats or an offshore structure (AAOT,

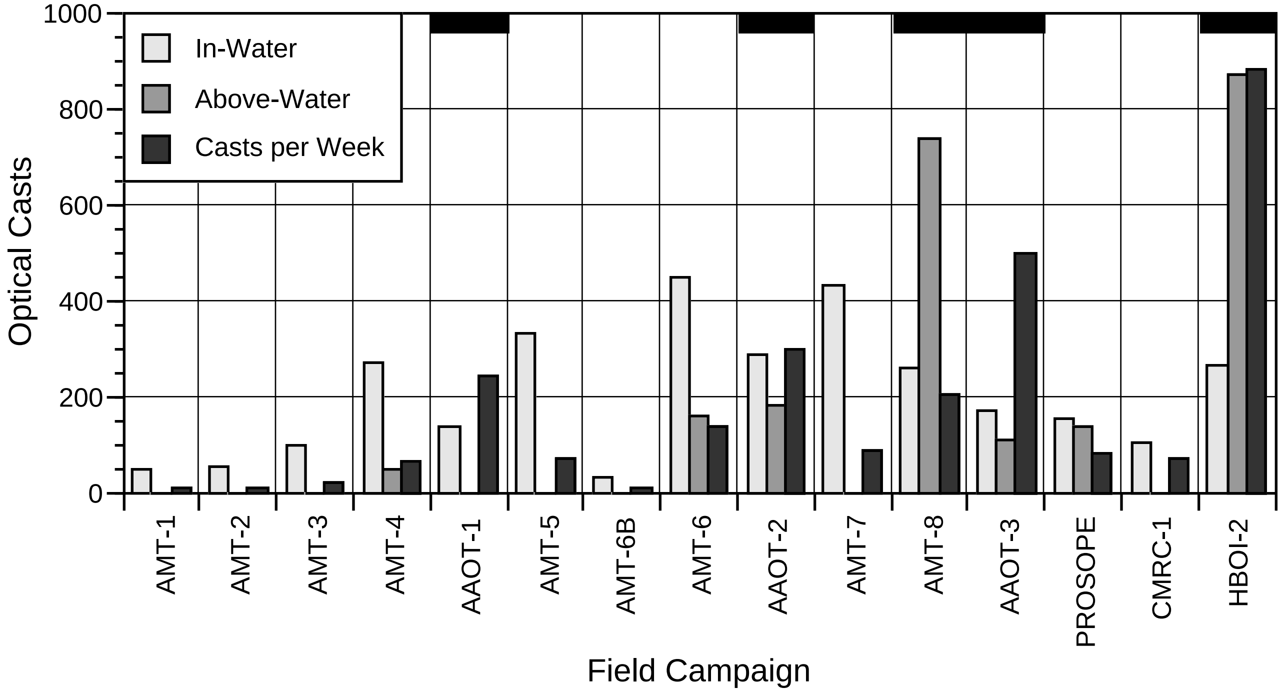

Fig. 9. The number of above- and in-water casts, plus the number of casts collected per week, executed by the SeaWiFS Field Team for a variety of deep and coastal ocean field campaigns. The dark bars along the top indicate the most productive deployments (more than 200 casts per week).

CMRC, and HBOI). Although the former frequently produce the largest number of casts, the latter almost always provide the best productivity, in terms of casts per week, as identified by the black bars at the top of the graphic.

The primary difficulties with the AMT cruises was an inability to dedicate time in targeted areas (to ensure bad weather does not render the opportunistic sampling fruitless), a total failure to secure the needed diplomatic permissions within the appropriate exclusive economiz zones, insufficient ship time to divert from the generalized cruise track, and the large amount of time spent in the tropics (which are very cloudy or contaminated with Saharan dust) resulted in very few validation match ups. After screening the data set using a number of quality control criteria, only about 1.4% of the AMT-5 in-water radiometric data could be used for satellite comparison (McClain et al. 1998). (Turbid water cases were not included in the analysis because high reflectance waters are known to introduce errors in the estimation of aerosol radiance and, subsequently, the L_W values.) Given the limited resources of the SeaWiFS Field Team, and the lack of progress in resolving the sampling issues that could be dealt with (like diplomatic clearances) but that were not, the decision was made to pursue other sampling opportunities.

The emphasis over the next year is to continue sampling in the coastal ocean, but to organize an expedition to resolve algorithm issues at low chlorophyll a concentration (Fig. 4). All of the cruises have as a first priority the collection of match up data for vicarious calibration. The match up time period is usually defined as within one hour of overpass; the time outside this period is used for specific experiments to address above- and in-water validation issues. The expected schedule is as follows:

1. Operational deployment of two or more SeaPRISM units on offshore towers during the summer of 2000;
2. A Case-2 SeaWiFS and MODIS validation cruise in the northern Adriatic Sea during July 2000 ((this will be in collaboration with JRC and will include HPLC pigments plus a suite of bio-optical measurements));
3. A Case-1 SeaWiFS and MODIS validation cruise in the Bahamas (Exuma Sound) during early 2001;
4. A Case-2 SeaWiFS and MODIS validation cruise in the northern Adriatic Sea during the spring bloom in 2001; and
5. A Case-1 SeaWiFS and MODIS validation cruise off the Ligurian Sea in the summer of 2001.

The field expeditions will include continuing validation of the new microNESS and microSAS sampling systems, and will include HPLC pigments plus a suite of bio-optical characterization measurements whenever possible. The experiments to determine which FOV is most appropriate for an above-water system will continue to be made when possible (the frame for this work requires a substantial mounting capability that will not be available on all types of small boats).

Data Archive and Access

SeaWiFS Field Team optical and pigment data are stored in the SeaWiFS Bio-Optical Archive and Storage System (SeaBASS) which is a well documented archival system (Hooker et al. 1994). The data are available to authorized users (which includes all those who contribute to the database), but cannot be made public or published without prior approval or participation of the owner (Hooker et al. 1993).

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